

Physics Case for the Energy Frontier

Andrei Gritsan

Johns Hopkins University & CMS/LPC

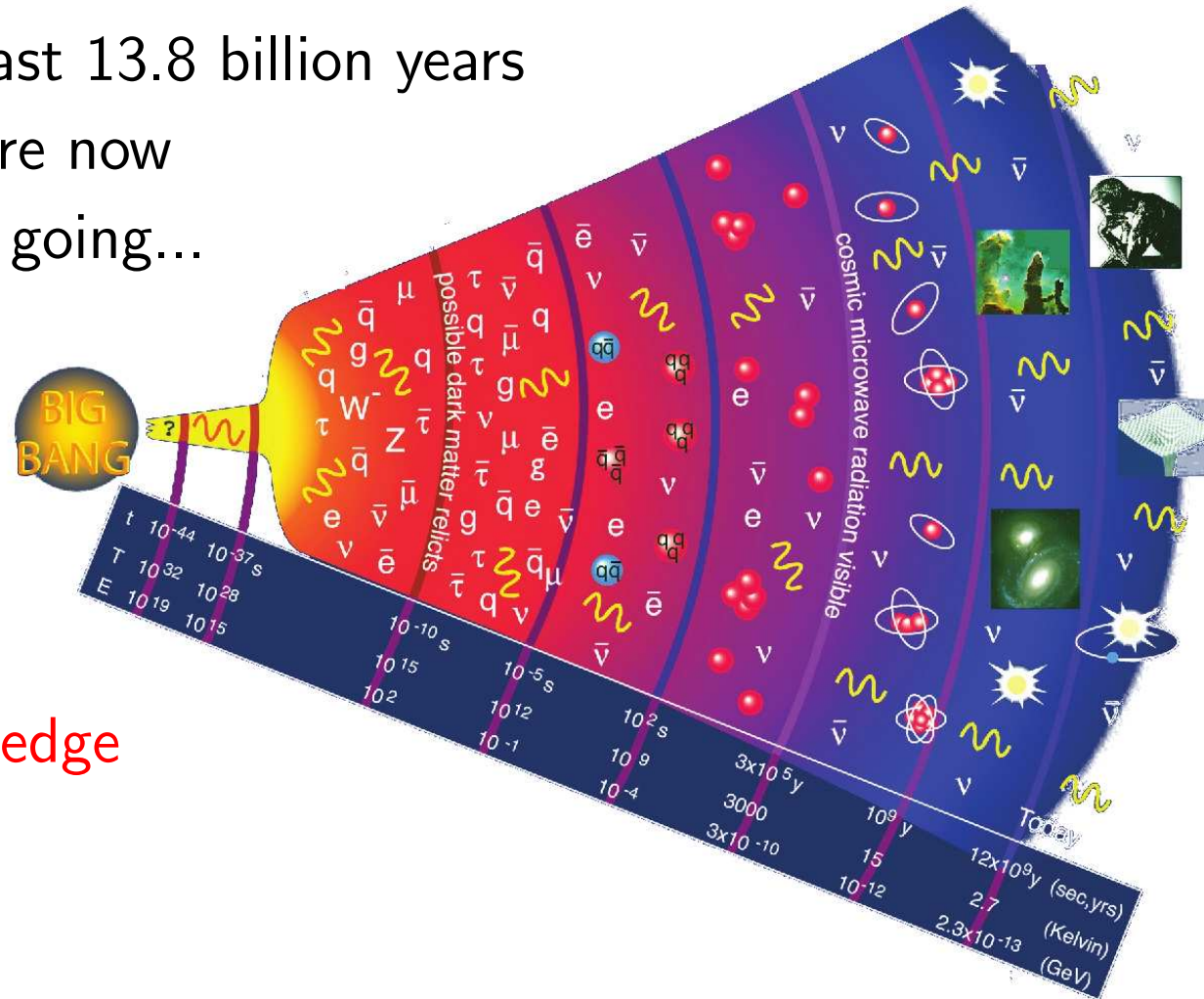
April 4, 2013

Panel Discussion on the Energy Frontier
Snowmass Energy Frontier Workshop

Brookhaven National Laboratory, Upton, NY

Why Pursue Energy Frontier

- First of all it is a **cultural** reason:
 - learn about the past 13.8 billion years
 - about where we are now
 - and where we are going...



- Stay on the **cutting edge**
 - of education
 - of technology
 - of fundamental scientific knowledge

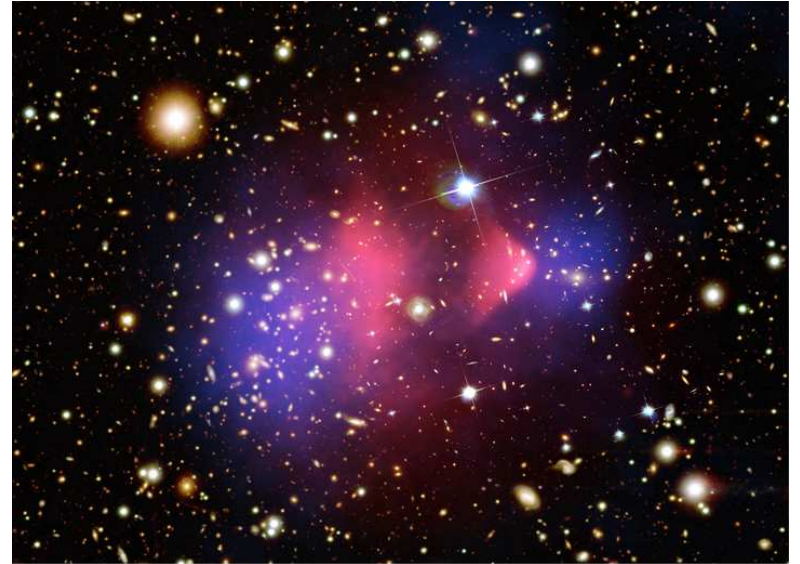
Discovery of a Higgs Boson

- Discovery of a Higgs Boson
 - absolutely new form of **matter-energy**
 - consistent with fundamental $J^P = 0^+$
scalar excitation of a **vacuum** field
- It would be foolish to stop here
 - is it the only such a state?
 - what does it tell us?
 - where does it lead us?
- It is also a triumph of **predictive power** of scientific knowledge
 - we knew where to look
 - but a discovery was **not guaranteed**, also true for the **next steps**



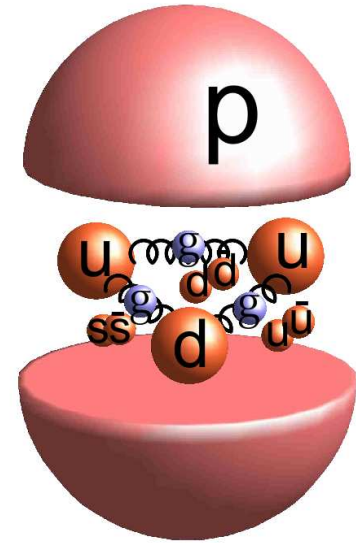
The dark questions: What we do not see

- What is in the vacuum?
 - **dark energy**, 10^{120} too small ?
 - $\sim 70\%$ of matter-energy balance
 - **Higgs field**, related to dark energy?
 - is vacuum (Higgs field) unstable?
- What is **dark matter**?
 - $\sim 25\%$ of matter-energy
 - is it a WIMP? does it interact with the Higgs field/boson?
- Where did **antimatter** go?
 - $\sim 0\%$
 - CP violation in the Higgs sector? anywhere else?
 - why is proton so stable?



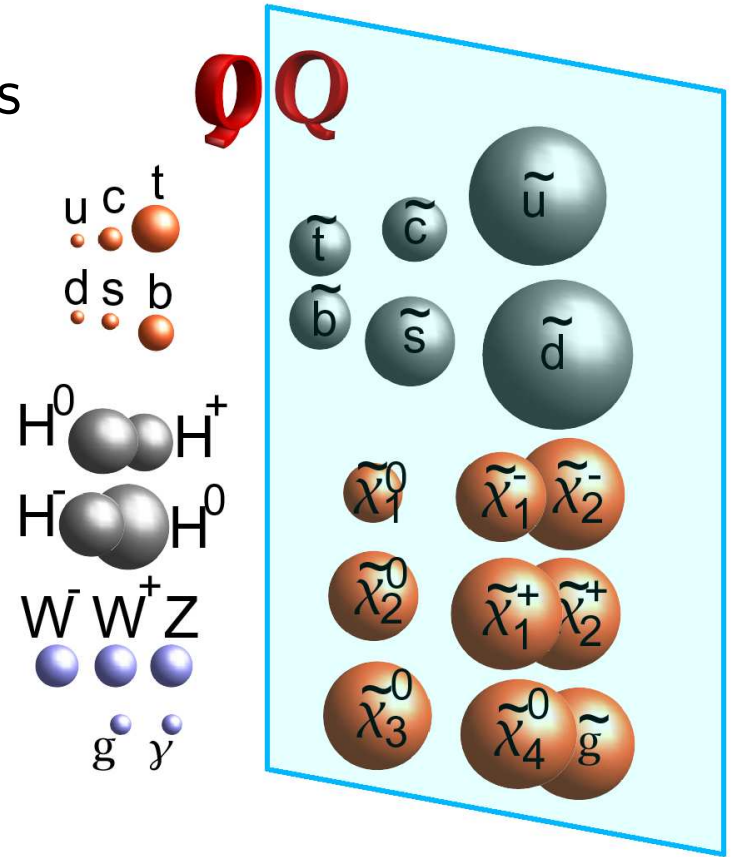
The light questions: What we do see

- We do not understand (see) 95% of the Universe
- But even what we do see:
 - why is **light** (γ) so light?
and does not see the Higgs field?
 - masses of fermions from $<1 \text{ eV}$ to $>10^{11} \text{ eV}$
are the Higgs field **couplings random**?
 - how do we keep the Higgs boson **stable**
against large radiative corrections?
 - why is **gravity** so weak? $\sim 10^{32}$ weaker than the weak force
do we understand the space-time? extra dimensions?
how do we approach quantum gravity? are there gravitons?



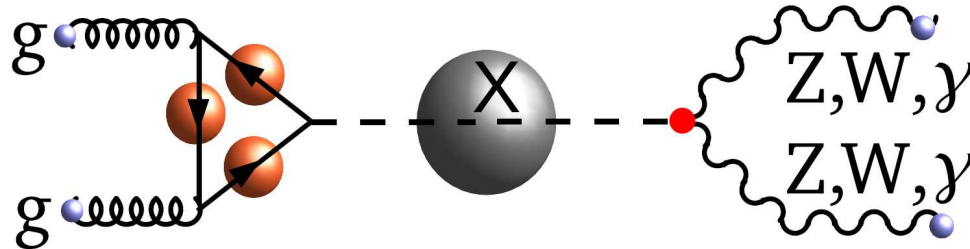
Looking for answers

- With so many questions, we need answers
- Motivated models exist
 - but must **confirm experimentally**
- Implications for the **Energy Frontier**
 - **Higgs boson** is not alone
 - its **properties** affected
 - **CP violation** observable
 - **dark matter** candidate
 - many partner particles may be **within reach** (direct or indirect)
- The reach depends on the **dial of Nature**
 - the whole new view on the Universe may open up
 - we are very **close to find out...**

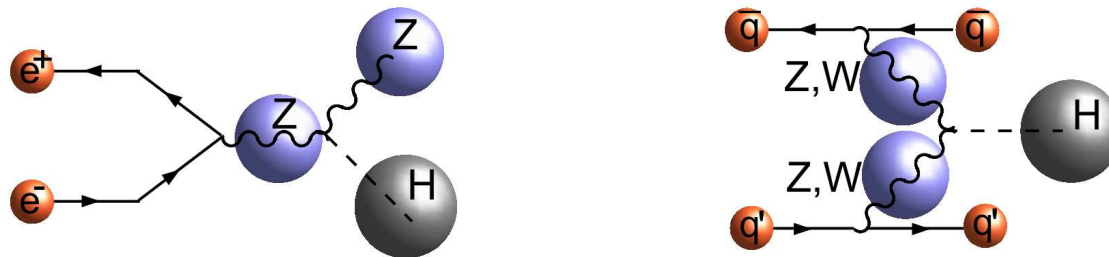


Two paths to reach

- We have seen this



- We are now guaranteed to have these



- Two paths to proceed

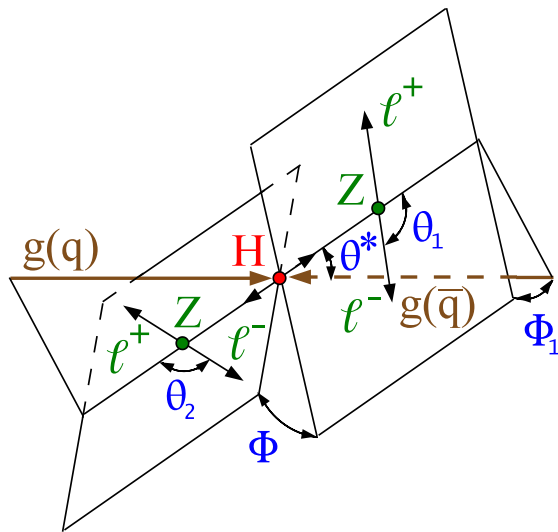
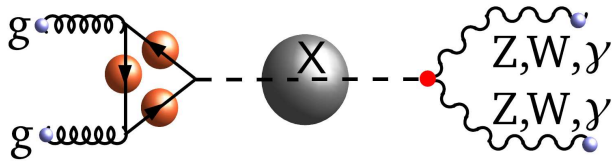
- (1) precision measurements of **new state** of matter-energy (**H**)
- (2) reaching higher in mass+sensitivity for **other states** (**X**)

5-10% precision on (1) \Leftrightarrow few TeV mass reach (2)

We have the knowledge and technology

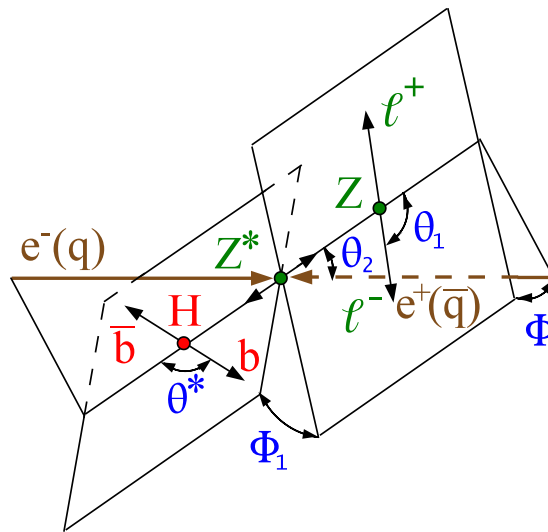
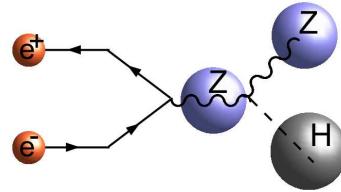
- LHC pp

$$gg \rightarrow H$$



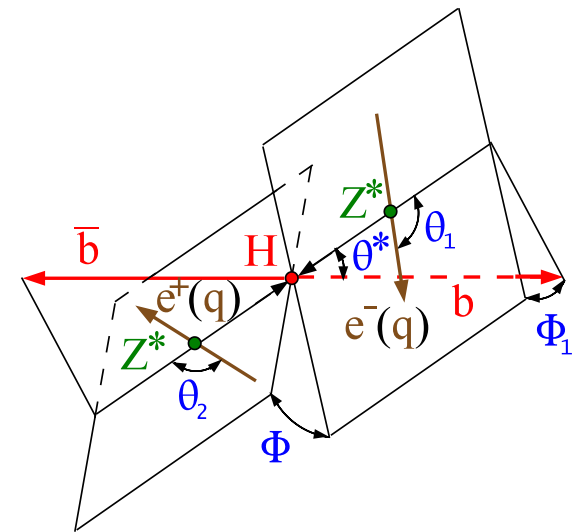
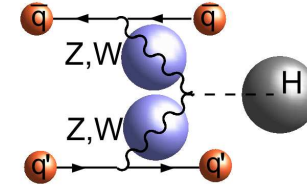
- H-factory ~ 250 GeV

$$e^+e^- \rightarrow Z^* \rightarrow ZH$$



- ILC ~ 1 TeV

$$e^+e^- VV \rightarrow \ell\ell H$$



- With complementary approaches
 - guaranteed **precision understanding** of the Higgs boson
 - when new discoveries happen, use facilities for **deep understanding**

Frontier facilities

5-10% precision on (H) \Leftrightarrow few TeV mass reach (X)

- This is a model-dependent statement, we need BOTH

- Exciting opportunities:

(1) LHC pp at 14 TeV

with further upgrade of lumi and possibly energy

(2) Linear e^+e^-

with further upgrade of energy

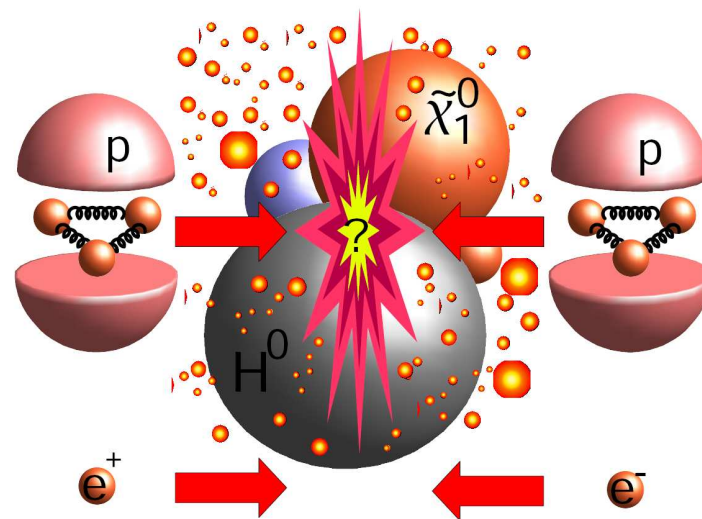
(3) Circular e^+e^-

with further upgrade to $pp \sim 100$ TeV

(4, 5) Muon and photon colliders

- Discoveries may be at reach but not guaranteed

we can guarantee (a) not to miss & (b) stay on the cutting edge



The other questions we face

- It all looks excellent, but
 - with limited support, where can we focus
- Questions to US community
 - join CERN for LHC lumi/energy upgrade (1)
 - join overseas e^+e^- machine (2)
 - have the next Energy Frontier facility in the US (3)
 - more than one (all) of the above
 - substitute Energy Frontier with “smaller alternatives”
- We have the Physics Case
 - make it sharp (Snowmass effort) and do the best we can...



Conclusion

- We have a very strong **Physics Case** for the **Energy Frontier**
- In my view, the biggest question to answer
 - **Why did not we discover the Higgs boson at the SSC?**

